Analysis of window model accuracy and its influence on the results compared to the measurement

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Abstract. This paper deals with differences between modelled window sash and frame in the Therm software and comparison with measured values in the pavilion type laboratory. In this laboratory are three different windows evaluated since 2011. These windows are suitable for low-energy or passive houses. Two different plastic based windows were modelled and the temperatures were compared to the real measurement with different outdoor temperatures.

1 Introduction

Window is an important part of building envelope. It has more functions than only protect the indoor environment against the outdoor climate like a non-transparent part of building envelope. Very important is the insolation of the space, views, contact with outdoor, ventilation, etc. With the more strict requirements of thermal properties it is necessary to increase the thermal properties of used materials, both for glazing (triple, gas fillings, heat mirrors and low emissivity surfaces) and frames (wooden, aluminium, plastic with thermo modules, more chambers etc.). Nonetheless the advance is incorporating the photovoltaics into the glazing or use of transparent thermal insulations [1]. Overcome of overheating is also a problem which has to be dealt with by the low-energy buildings [2]. Another problem is the minimizing of thermal loss through the thermal bridges around the windows [3]. The use of triple glazing helps to avoid the cool radiation from the glass surface and also the vapor condensation at the bottom of the glazing.

The Slovak standard [4] dealing with thermal protection (STN 73 0540:2012) followed the EC directive about Energy performance of buildings (EPBD) 2010/31/EU [5]. Valid values for windows are since 2016 $U_w = 1.0$ W/(m^2.K) and from 2021 it will be on the level 0.6. The windows, which are modeled in this paper, meet the standard for ultra-low energy buildings which is valid nowadays. The U_w value is not the only criterion which has to be met. Minimal indoor surface temperature requirement is the other one. This requirement is divided for windows and for non-transparent structures such as walls etc. Required values are stated also in [4].

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During the designing stage of building development, temperature analysis of thermal bridges has to be made for multiple fragments. This also incorporates details with the window frame, sash and position in the opening with different wall types and insulation.

Modelling of the different window frames /sash create difficulties in the civil engineering practice. Exact modeling of plastic and metal frames is time consuming. In the area of two dimensional building heat-transfer modeling are multiple software available. In Slovakia, possible most used is commercially available software Area from Svoboda software [6]. This software has library with multiple modelled window frames, but mostly there are simple wooden window with double glazing only.

In this article was used Therm [7] software, developed at Lawrence Berkeley National Laboratory. With combination of Window program [7], very precise analysis of glazing system can be inserted into the simple window frame. Detailed models of two different plastic windows were compared to the real windows. These types are evaluated in the laboratory of Department of Building Engineering and Urban Planning since 2011[8]. This laboratory has the controlled indoor environment and outdoor climate is real and recorded with weather station [9]. Temperatures from software and measurement were compared and results stated.

2 Windows specification

For the comparison of modeled and measured temperatures two plastic windows were used. These windows differ from each other with integrated insulation within the frame. In the Table 1 are summarized properties. Although the glazing has different filling, the U_g value is the same. Different is the heat gain. The integration of thermo modules from graphite polystyrene in the frame and sash lowered the U_f value from 1.0 to 0.85. Detailed view on the frame and sash profiles is shown in Figure 1.

Windows are built-in into the exterior wall of the pavilion type of laboratory. The maintained indoor environment has temperature set close to 20 °C, which is standard temperature according to the Slovak standard [4]. During very cold winter night the real temperature is about 17 °C. This is taken into account during the comparison. The windows are equipped with multiple thermocouples from both sides (estimated 60 pcs.) and several heat flux plates. This enables the possibility to compare the windows directly [8, 10]. Comparison with numerical modelled values such as in this case was not made yet.

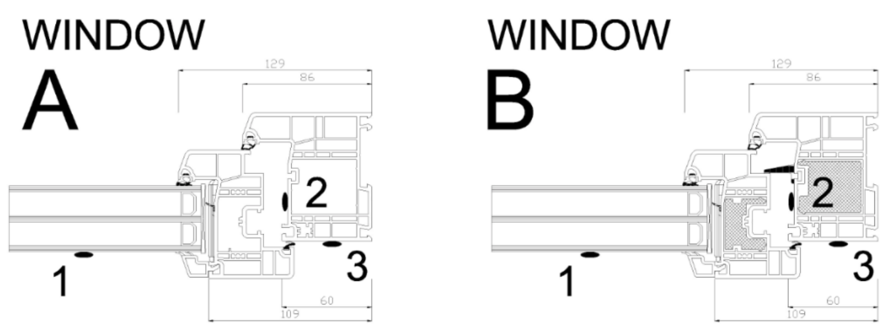

Fig. 1. Detailed view at window frame and sash for two windows. Marked positions for comparison.

Table 1. Specified properties of measured windows based on the manufacturers data.

Window	**Material**	**Number of chambers**	**Gas filling**	**Heat gain [%]**	U_w **calculated**	U_f	U_g
					[W/(m^2.K)]		
A	plastic	6	Ar	36	0.80	1.0	0.5
B	plastic with thermo modules	6	Kr	47	0.78	0.85	0.5

3 Modelling of windows in Therm and Window software

Modeling of the plastic window frames was done in the Therm 7.6 software [7]. This software is ease to use and with possibility of importing the exact geometry from the AutoCADs .dxf file any complex geometry can be modeled. To achieve the best performance of the glazing system, Window 7.6 software [7] was used. This is a complex software for creating the glazing system consisting of exact glass panel, cavities with gas fillings etc. Low emissivity glass are crucial in the term of decreasing the thermal losses. Because of not knowing the exact glass types, triple glazing (matching to known 4-16-4-16, Ar) was modeled from Window library. Saint-Gobain Glass SGG Planitherm Ultra N II was selected. Calculated value $U_g = 0.58$ W/(m^2.K) is close to the manufacturers one (Table 1). Detailed view at window frames and sashes is presented in Figure 1. These windows were placed in the exact same wall composition as those in the laboratory to obtain the best match of temperatures (Fig. 2).

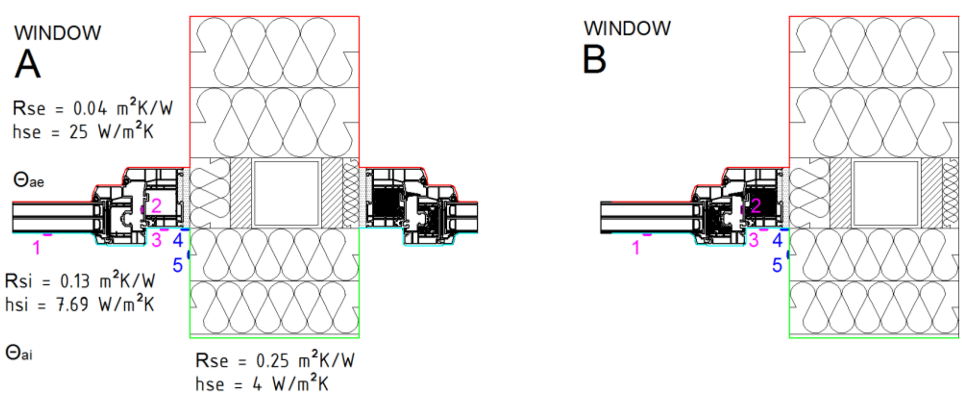

Fig. 2. Window A and B in the positions within the laboratory wall openings. Five marked positions for temperature comparison and surface coefficients of heat transfer [4].

The cavities in the plastic frame create another difficulties in the modeling. In fact, they are filled with air and should be calculated as closed air cavities with different thermal resistance. In reality, the heat transfer is more complex and there is not only convection as in solid material. To observe the difference between these two principles of solving the cavities, both variants were modeled. The frame modeled with cavity function is named CAVITY, modeled as solid material is named SOLID. Detailed structure of frame with different conductivities are shown in Figure 3. The rest of materials used for the window, frame and wall structure have known thermal conductivity coefficient. Most of them were available from the window manufacturer and they are summarized in Table 2.

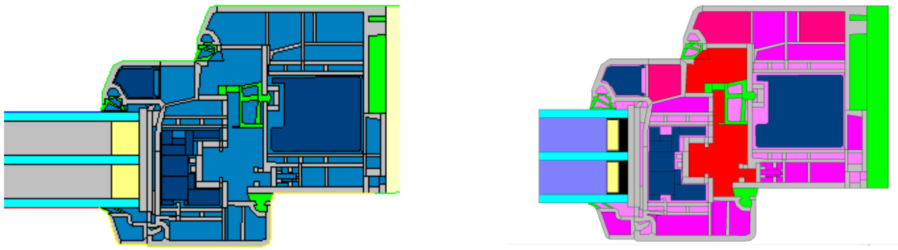

Fig. 3. Left - cavities modeled with the program function cavity - CAVITY, right - cavities in frame and glazing modeled as solid materials with different conductivities according to the thickness of the cavity [4] - SOLID.

Table 2. Thermal conductivity coefficient used in the software Therm.

Name and material	**Thermal conductivity coefficient λ [W/(m.K)]**	**Material**	**Thermal conductivity coefficient λ [W/(m.K)]**
PVC - frame profile	0.17	Gas filling Argon	0.017
EPS graphite polystyrene	0.035	Air cavity th. 2.5 mm	0.041
glass seal	0.24	Air cavity th. 7 mm	0.054
frame/ sash seal EPDM	0.25	Air cavity th. 10 mm	0.067
Spacer - Stainless steel	17	Air cavity th. 15 mm	0.088
Spacer fill	0.10	Air cavity th. 50 mm	0.280
XPS polystyrene	0.036	Glass	0.76
Steel frame	50	Wood profile	0.13

There are three thermocouples placed within the window itself (Fig. 1) and two more on the side jamb and in the montage cavity filled with polyurethane spray foam (Fig. 2).

4 Results and discussion

Totally two variants from both windows which differ with methodology of cavity calculation were modelled. Five positions were monitored according to the real measurement. Three different values of outdoor temperature were used. According to the Slovak standard [4], for location of Zilina design temperature of outdoor air is - 15 °C. This temperature is reached several times during the winter. For this comparison were used - 16.7, -10 and - 5 °C to observe the differences by the individual temperatures.

The boundary conditions and the results are summarized in Table 3. Infrared color map of detail for outdoor air temperature - 16.7 °C, SOLID and CAVITY variants are in Fig. 4 for window A and Fig. 5 for window B.

Table 3. Results of measurement with three different air temperatures and numerical models SOLID and CAVITY.

	Position	Temperature		Measurement	SOLID	CAVITY
Window A	1	outdoor -16.7	indoor 18.0	13.2	13.8	15.7
	2			-0.7	-0.4	0.1
	3			8.4	11.9	10.6
	4			8.2	13.6	13.5
	5			14.5	16.8	16.6
Window B	1			12.7	13.7	15.7
	2			3.9	3.5	1.8
	3			12.1	13.4	13.5
	4			11.6	14.2	14.2
	5			16.1	16.7	16.7
	Position	Temperature		Measurement	SOLID	CAVITY
Window A	1	outdoor -10.0	indoor 19.3	15.1	15.8	16.6
	2			4.3	3.8	4.2
	3			11.5	14.3	13.3
	4			11.5	15.6	15.2
	5			16.2	18.2	17.2
Window B	1			14.3	15.8	16.9
	2			8.0	5.2	5.6
	3			14.1	15.9	15.0
	4			13.7	16.1	16.1
	5			17.2	18.2	17.9
	Position	Temperature		Measurement	SOLID	CAVITY
Window A	1	outdoor -5.0	indoor 19.0	15.6	14.8	17.4
	2			6.2	6.3	6.8
	3			12.1	14.9	14.4
	4			12.0	15.9	15.9
	5			16.5	18.2	18
Window B	1			15.1	14.9	17.4
	2			8.7	7.7	6.8
	3			14.7	16.2	15.9
	4			14.2	16.4	16.4
	5			17.4	18.1	18.1

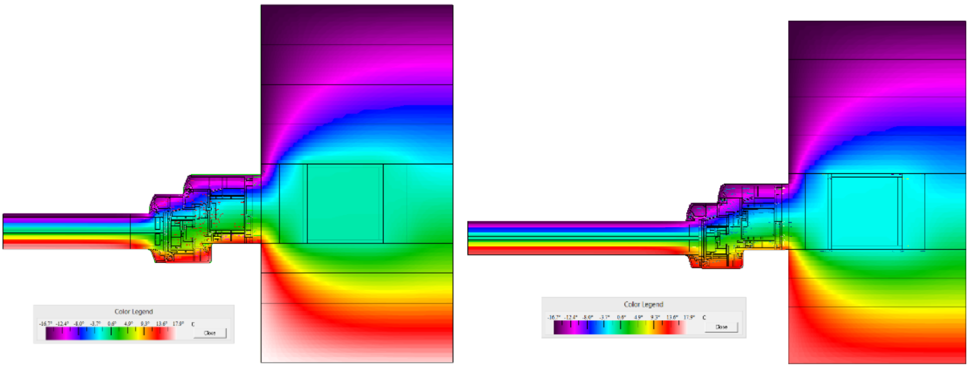

Fig. 4. Window A. Left SOLID, right CAVITY. Biggest difference can be seen on the glazing and sash - where is the widest air cavity. Window A has no middle seal.

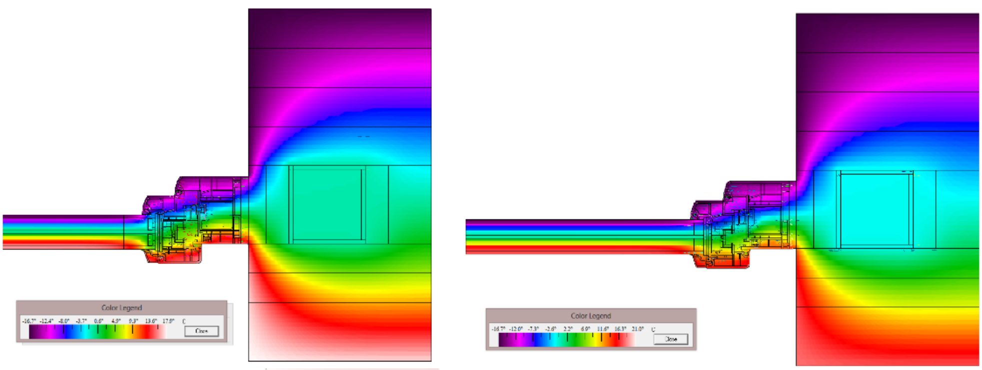

Fig. 5. Window B. Left SOLID, right CAVITY. Biggest difference can be seen on the glazing and sash, where the air cavity is filled with graphite polystyrene, middle seal result is higher temperature in the cavity between frame and sash.

Some positions have very similar results between both models and measurement, some differ considerably. Highest difference is up to 2.5 °C. The results (Table 3) between the models SOLID and CAVITY showed differences, which are not the same. If we talk about the temperature on the glazing, the exact-modeled glazing system showed higher surface temperatures and the position near the frame is not such influenced as in the SOLID case. This position has the biggest differences between the SOLID and CAVITY model (up to 2.5 °C). Compared to the measured values, the SOLID model temperatures are closer to the measured values.

The position in the cavity between frame and sash are different for both windows because of the lack of middle / central seal in window A. This make in measured values, between window A and B, up to 4.5 °C by the lowest temperature and 2.5 °C by the smaller differences. Which model is better for this position is not easy to say, because by different temperature the results are different for the window B. For window A, without the seal, the match is better with the SOLID model.

Position on the inner surface of sash has the biggest differences from the both models. Both models have similar or exact values for this positions. The position four on the surface of montage cavity filled with polyurethane foam showed that the temperatures from SOLID and CAVITY matched, but both are higher than measured ones. This is probably caused by the better conductivity of foam in the model. Last position, on the window jamb has similar results and this position is not influenced by the model so far, because of the distance from any cavity/ not solid material area. Differences from measurement are up to 1 °C.

5 Conclusion

Two windows with two different model approaches were modeled in the Therm software. For the comparison, five positions and three various outdoor temperatures were compared. The results showed biggest difference for the glazing itself, both for the model / measurement and also for the SOLID / CAVITY models. The result showed overestimating the temperature on the glazing.

Use of SOLID / CAVITY models showed differences in all position on the frame, but not such significant except the position 2 on the window B. It seemed that for the plastic window the difference is not significant when the model is simplified with solid closed air cavities instead of modeling the cavities. Another simplification could be use of solid frame from some generic material. This type will be investigated in the future.

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